

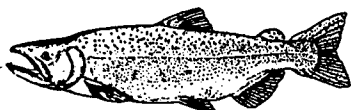
**IDENTIFICATION OF THE INSTREAM FLOW REQUIREMENTS  
FOR ANADROMOUS FISH IN THE STREAMS WITHIN  
THE CENTRAL VALLEY OF CALIFORNIA**

**Annual Progress Report  
Fiscal Year 1996**

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Prepared by staff of  
The Instream Flow Assessments Branch



## **PREFACE**

The following is the second annual progress report prepared as part of the Anadromous Doubling Plan Instream Flow Investigations, a 5-year effort which began in February, 1995. Title 34, Section 3406(b)(1)(B) of the Central Valley Project Improvement Act, P.L. 102-575, requires the Secretary of the Interior to determine instream flow needs for anadromous fish for all Central Valley Project controlled streams and rivers, based on recommendations of the U.S. Fish and Wildlife Service (FWS) after consultation with the California Department of Fish and Game (CDFG). The purpose of this investigation is to provide reliable scientific information to the U.S. Fish and Wildlife Service Central Valley Anadromous Fish Restoration Program to be used to develop such recommendations for Central Valley rivers.

To those who are interested, comments and information regarding this program and the habitat resources of Central Valley rivers are welcomed. Written comments or information can be submitted to:

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## INTRODUCTION

In response to substantial declines in anadromous fish populations, the Central Valley Project Improvement Act requires the doubling of the natural production of anadromous fish stocks, including the four races of chinook salmon (fall, late fall, winter, and spring), steelhead trout, and white and green sturgeon. In December 1994, the USFWS, Ecological Services, Instream Flow Assessments Branch prepared a study proposal to use the Service's Instream Flow Incremental Methodology (IFIM) to identify the instream flow requirements for anadromous fish in selected streams within the Central Valley of California. Subsequently, as discussed in our first annual report, the Sacramento, lower American and Merced Rivers were selected for study. The studies on these rivers have been and will continue to be closely coordinated with study efforts being conducted by CDFG.

The Sacramento River study is a five-year effort to be concluded in September, 1999. Specific goals of the study are to determine the relationship between streamflow and physical habitat availability for all life stages of chinook salmon (fall-, late fall-, winter-, and spring-runs) and steelhead trout; and to identify flows at which redd dewatering and juvenile stranding conditions occur. The instream flow requirements for white and green sturgeon may also be studied; however, the inclusion of these species depends upon the availability of resources and sufficient data to enable identification of the habitats used by them. The study components include: 1) compilation and review of existing information; 2) consultation with other agencies and biologists; 3) field reconnaissance; 4) development of habitat suitability criteria (HSC); 5) study site selection and transect placement; 6) hydraulic data collection; 7) construction and calibration of reliable hydraulic simulation models; 8) construction of habitat models to predict physical habitat availability over a range of river discharges; and 9) preparation of draft and final reports. The FY96 Scope of Work (SOW) identified study tasks to be undertaken. These included: field reconnaissance (study component 3); study site selection, transect placement, and hydraulic data collection (study components 5 and 6); and continuing the development of HSC (study component 4). During FY96, an additional study task was added: Young-of-the-year (YOY) chinook salmon habitat use and behavioral characteristics. The objectives of this study element were to: 1) determine if any of the mesohabitat types identified by CDFG are particularly important as rearing habitats for chinook salmon fry and juveniles (YOY); 2) observe and quantify YOY habitat use in like mesohabitats longitudinally on the river; 3) observe and quantify ontogenetic shifts in YOY habitat use; 4) observe downstream migration patterns; and 5) examine YOY use of various structural elements (i.e. cover) and the availability of these elements in each mesohabitat type.

The lower American River study was a one-year effort to be concluded by March 31, 1996 as indicated in the FY96 SOW. The purpose of this study was to produce a habitat model predicting physical habitat availability for spawning fall-run chinook salmon and steelhead trout. This information was to supplement data which have been collected by CDFG for several years to produce comprehensive instream flow recommendations. A report detailing the methods and

results of this effort was submitted to CDFG on March 27, 1996 for enclosure in their final report on the lower American River. Study components included: 1) field reconnaissance and selection of study sites; 2) placement of transects in selected study sites; 3) hydraulic data collection; 4) construction and calibration of reliable hydraulic simulation models; 5) construction of habitat models to predict spawning habitat availability over a range of river discharges; and 6) preparation and submittal of a report detailing study procedures and model results. A copy of the report was also provided to staff of the CVPIA Anadromous Fish Restoration Program.

The Merced River study is a 1.5 year effort which was scheduled to begin in October, 1995. The purpose of this study is similar to that for the lower American River study described above - to produce a habitat model predicting physical habitat availability for spawning fall-run chinook salmon. This information will also supplement data which have been collected by CDFG for several years to produce comprehensive instream flow recommendations. Habitat model results will be submitted to them for enclosure in their final report on the Merced River. The study components include: 1) field reconnaissance and selection of study sites; 2) placement of transects in selected study sites; 3) hydraulic data collection; 4) construction and calibration of reliable hydraulic simulation models; 5) construction of habitat models to predict spawning habitat availability over a range of river discharges; and 6) preparation and submittal of a report detailing study procedures and model results.

The following sections summarize project activities between October, 1995 and September, 1996.

## **SACRAMENTO RIVER**

### **Field Reconnaissance and Study Site Selection**

Field reconnaissance in FY96 began to reveal potential study sites where habitat modelling will be undertaken for chinook salmon spawning and rearing. No final selections of study sites have been made yet. The following two sections describe the methods employed and the results of FY96 reconnaissance efforts for these two life stages.

#### ***Chinook salmon spawning habitat***

##### **Methods**

The latest six years of aerial redd survey data collected by Frank Fisher (CDFG) for each of the four runs of chinook salmon were analyzed to determine the most heavily used spawning mesohabitat units (primarily riffles). Insufficient data were available for spring-run chinook salmon. This race is thought to be primarily a tributary spawner and it has proven impossible to differentiate those that do spawn in the mainstem from fall-run adults present at the same time.

For the other three races, the mesohabitat units were ranked in each of the stream segments<sup>1</sup>, to identify those areas which consistently received the heaviest spawning use. Many of these areas were reconnoitered during October and November, 1995.

## Results

Segment 6 appears to be important primarily for late fall-run spawning, with 24% of the late fall redds in this segment. Segments 5 and 4 are important for all three races with, respectively, 35% and 12% of fall-run spawners, 51% and 8% of late fall spawners, and 80% and 3% of winter-run spawners. Segments 3 and 2 are primarily important for fall-run spawning with, respectively, 15% and 23% of the fall-run spawners. Modelling spawning habitat for these races in the above segments will include most of their spawning areas with a total of 85% of the fall-run, 83% of the late fall-run, and 83% of winter-run spawning. The results of the ranking of mesohabitat units based on aerial redd survey data are shown in Table 1. Field reconnaissance indicated that some of the mesohabitat units listed in Table 1 are no longer receiving much spawning use and do not appear to have suitable substrates for spawning. As a result, we plan to modify our list of potential chinook salmon spawning study sites based on CDFG's analysis of aerial photographs for redd counts, and additional field reconnaissance during the FY97 spawning seasons.

## *Chinook salmon rearing habitat*

The reconnaissance activities undertaken for this life stage fall under the description of the additional study task added in FY96. The objectives of this study element (Young-of-the-year (YOY) chinook salmon habitat use and behavioral characteristics) are given in the Introduction of this report.

## Study Area

The study area extended from the Anderson-Cottonwood Irrigation District Diversion Dam (ACID) at river mile (RM) 298.5 to the mouth of Battle Creek (RM 271.4). Battle Creek was chosen as the downstream terminus to preclude the inclusion of juvenile chinook salmon released at the Battle Creek National Fish Hatchery, and the effects these fish might have on naturally produced YOY habitat selection, in the data.

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<sup>1</sup> As discussed in the FY95 annual report, we have divided the Sacramento River study area into six stream segments, based on hydrology and other factors: Grimes to Colusa (Segment 1); Deer Creek to Red Bluff Diversion Dam (Segment 2); above Lake Red Bluff to Battle Creek (Segment 3); Battle Creek to Cow Creek (Segment 4); Cow Creek to ACID (Segment 5); and ACID to Keswick (Segment 6). Segment 1 addresses green and white sturgeon, while the other segments address chinook salmon.

Table 1  
Top-ranked Mesohabitat Units for Chinook Salmon Spawning  
Based on Aerial Redd Survey Data

Stream Segment	River Mile	Location <sup>2</sup>	Races <sup>3</sup>
6	298.5-298.9	Lake Redding below RR Bridge	LF
6	299-300	Lake Redding above RR Bridge	LF
6	300.8	Salt Creek	LF
6	300.2		LF
5	295.9-296.1	299 Bridge Riffle	F, LF, W
5	287.9-287.5	Joe Dearing/Knighton Riffles	F
5	297.2	Turtle Bay West	F, LF
5	297.6-297.9	Posse Grounds Riffle	F, LF, W
5	282.8-282.6	Above Hawes Hole	F, LF
5	298.3	Bridge Riffle	F, LF, W
5	291.8-291.3	Tobiasson Riffle	W, (F, LF)
5	296.6-296.8	Palisades	W
5	293.4-293.6	Canyon Creek (Golf Course #9)	W
4	279.3-279	Powerline Riffle (Powerline #7-9)	F, LF, W
4	277.5-277.3	Bear Creek	F
4	276.1-275.7	Balls Ferry Riffle	F, LF
4	271.8-271.6	Price Riffle	F, LF, W
4	273.4-273	Cottonwood Riffle	F, LF, W
4	279.7		LF
3	279.3-279	Powerline Riffle (Powerline #7-9)	F, LF, W
3	277.5-277.3	Bear Creek	F
3	276.1-275.7	Balls Ferry Riffle	F, LF
3	271.8-271.6	Price Riffle	F, LF, W
3	273.4-273	Cottonwood Riffle	F, LF, W
3	279.7		LF
2	240.3-240.7	Osborne Riffle (Pipeline #1-2)	F
2	239.2-239.5	Blackberry Riffle	F
2	222.9-223.2	Five Fingers Riffle	F
2	241.5-241.8	Pipeline Riffle (Pipeline #6-8)	F
2	222.5		F

<sup>2</sup> Information in parentheses refers to CDWR instream flow study transects.

<sup>3</sup> F = fall-run, LF = late fall-run, W = winter-run. Races in parentheses were not ranked among the highest for that stream segment, but are included because they used the mesohabitat unit relatively heavily and the mesohabitat unit was ranked high for another race.

## Methods

Habitat typing conducted by CDFG identified 12 specific mesohabitat types and a total of 142 mesohabitat units in the 27.1 mile section of the Sacramento River between ACID and Battle Creek. This section was divided into three segments, each approximately nine miles long. One unit of each mesohabitat type (excluding side-channel pools) were randomly selected from each segment as study sites. Side-channel pools were excluded because there were only two in the entire study area. In addition, there were no side-channel glides in the entire study area. If a mesohabitat type was not found in one of the segments then one was selected from another segment so that each type was equally represented. The only exception to this was, due to an error in classification of one mesohabitat unit, four side-channel riffles and two side-channel runs were sampled. Table 2 shows the mesohabitat type, number, and location of the study sites selected. There were fewer study sites in the furthest downstream segment (Segment 3). This is a result of the elimination of some of the sites selected in this segment because turbidity, particularly early in the year, rendered these sites impossible to sample effectively, and because some mesohabitat types are not present in Segment 3.

In early January, 47.5 m (150 ft) longitudinal transects were set up at each study site along both river banks by placing fluorescent markers at the up and downstream ends. To reduce bias in transect placement and avoid the influence of mesohabitat boundary effects, all transects were placed 30 m above the bottom boundary of the mesohabitat unit (as determined from areal photographs). Five sites were divided between different mesohabitat types in the middle of the river. For these sites (#'s 130, 118, 101, 70, 42) only one bank was sampled. Work began on January 10 with the intention of sampling all sites every other week. However, winter storms produced extremely high flows for an extended period from late January through most of March and poor sampling conditions caused by turbid tributary inflow resulted in a more irregular schedule. Eleven sampling trips had been made at the time of this writing. The dates of these trips, river discharge, and number of sites sampled are presented in Table 3.

At each study site divers using snorkeling gear would move slowly up the transects counting all fish observed between the waters edge and as far out as visibility allowed (visibility ranged from three to eight feet during the study period and was generally more restricted downstream). Each transect was divided into eight segments of approximately equal length and data were recorded separately for each segment (cell). Initially, a pair of divers (one adjacent to the edge and the other positioned within view towards mid-channel) would conduct the sampling. After a limited time, however, it was recognized that the outside diver was rarely observing any fish in the swifter waters present there while the inside diver was observing many. It appeared obvious that YOY salmon preferred the habitat conditions near the edge of the river. It was also obvious that the outside diver, without the ability to pull himself upstream using the structural elements found near the bank, was going to have trouble traversing the transect when flows were higher. Therefore, the decision was made that only one diver would sample each transect. When possible, this diver would move laterally from the edge towards mid-channel. Fish lengths,

Table 2  
Chinook salmon YOY sampling habitat units and locations  
on the Sacramento River in 1996.

Habitat Type		Segment 1 <sup>4</sup>		Segment 2 <sup>4</sup>		Segment 3 <sup>4</sup>	
		Habitat #	RM	Habitat #	RM	Habitat #	RM
Bar Complex	Run	111	294.5	62	287.2	22 <sup>5</sup>	278.3
Bar Complex	Riffle	132	297.3	75	289.0	30	279.9
Bar Complex	Pool	130	297.1	none	-	28	279.6
		118 <sup>6</sup>	295.0	-	-	-	-
Bar Complex	Glide	110	294.4	38	281.7	-	-
		-	-	70 <sup>7</sup>	288.6	-	-
Flat Water	Run	122	296.1	52	285.8	25	278.6
Flat Water	Riffle	135	297.6	55	286.5	17	277.3
Flat Water	Pool	101	292.4	42	282.2	15	276.8
Flat Water	Glide	99	291.7	51	285.8	27	279.1
Side Channel	Run	93	291.0	none	-	none	-
		82	289.5	-	-	-	-
Side Channel	Riffle	128	297.0	76	289.3	none	-
		92	290.9	-	-	-	-
		83	289.7	-	-	-	-
Off Channel	Area	79	289.4	37	281.4	none	-
				35	281.2	-	-

<sup>4</sup> Segment 1 extends from ACID (RM 298.5) to near Olney Creek (RM 289.5), segment 2 extends from Olney Creek to below Deschutes Road (RM 280.5), segment 3 runs from below Deschutes Road to Battle Creek (RM 271.4).

<sup>5</sup> Habitat Unit 22 replaced unit 2 (5/22/96) because unit 2 was located below Battle Creek.

<sup>6</sup> Unit 118 replaced unit 5 (6/10/96) because unit 5 was located below Battle Creek.

<sup>7</sup> Unit 70 replaced unit 7 (7/31/96) due to visibility and travel distance.



determined with the aid of a scale on the PVC wrist cuffs used to record data, were recorded in 10 mm increments. In addition to fish counts, the dominant cover type was described and recorded in each of the eight cells along the transects during each sampling date. A cover coding system was developed to describe the cover elements found in the river (Table 4). All data were transferred to field notebooks immediately upon completion of each dive.

Table 3  
Summary by week of the Sacramento chinook salmon YOY sampling during 1996.

Week <sup>8</sup>	Date	Keswick Release (cfs)	Number of Sites	Total Fish Counted	%<40 mm	%40-50mm	%50-60mm	%60-80mm	%>80mm
2	1/10	5,000	14	3020	100	0	0	0	0
12	3/20	8,000	26	271	18	30	40	2	0
15	4/8	5,000	30	1302	42	39	2	3	0
17	4/22	5,000	30	1543	31.9	43.5	20.7	3.8	0
19	5/6	7,000	33	4885	21.2	49.8	21.4	7.5	0
23	6/10	14,000	33	3711	23.1	29.4	33.9	12.2	1.3
25	6/25	12,000	33	2172	12.9	25.5	42.9	14.7	3.9
27	7/10	15,000	31	1707	3.2	35.3	43.5	17.9	0.1
29	7/31	15,000	32	2964	0.3	30.5	54.2	15	0
31	8/14	15,000	32	1253	1.7	44.3	31.3	16.3	6.4
33	8/26	15,000	32	1970	14.4	23	23.2	27.6	11.8
35	9/10	10,000	32	682	5.4	11.1	31.7	38.9	12.9

<sup>8</sup> Sampling continued in FY96 (after 9/10) following the preparation of this report.

Though the river channel away from the banks appeared inhospitable for young salmon, attempts were made to observe fish in this portion of the river. One method employed the use of a grappling anchor attached to a 45.7 m length of rope. The anchor was set 10 to 20 meters out from the bank at the top of each transect. Divers used a hand ascender to pull themselves up the rope, angling their bodies to move laterally. This method (tried during sample weeks 21, 23, and 25) worked well in water up to 6 ft deep with velocities up to 4 ft/s. Faster water could not be sampled efficiently but it was possible to sample deeper pool habitats using SCUBA gear. This method was used during week 23 in Turtle Bay where three divers spent approximately 30 minutes each looking for YOY chinook salmon in water up to 25 ft deep. Only one YOY salmon was observed during any of these attempts.

Table 4  
Cover Coding System

Cover Category	Cover Code <sup>9</sup>
no cover	0
cobble	1
boulder	2
fine woody vegetation (< 1" diameter)	3
branches	4
log (> 1' diameter)	5
depth (> 3' from surface)	6
overhead cover (< 2' from water surface)	7
undercut bank	8
aquatic vegetation	9
rip-rap	10

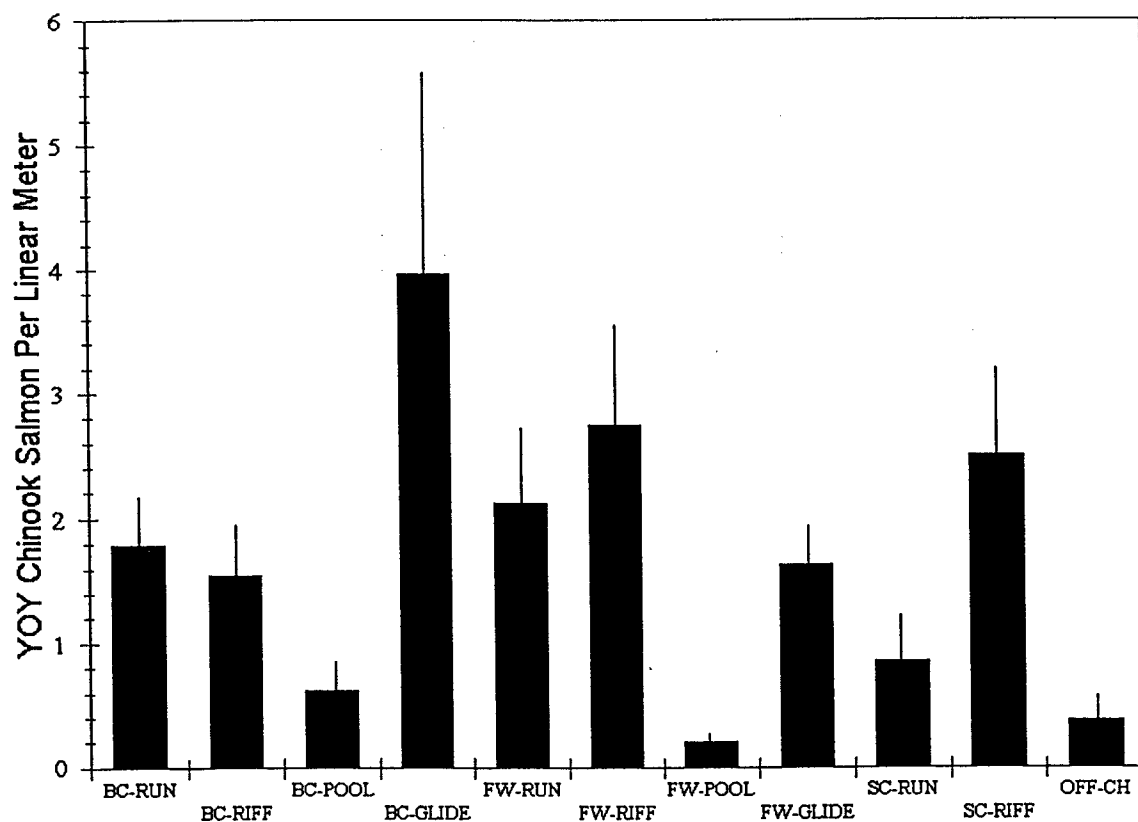
<sup>9</sup> In addition to these cover codes, we have been using composite cover codes; for example, 4/7 would be branches plus overhead cover.

## Results

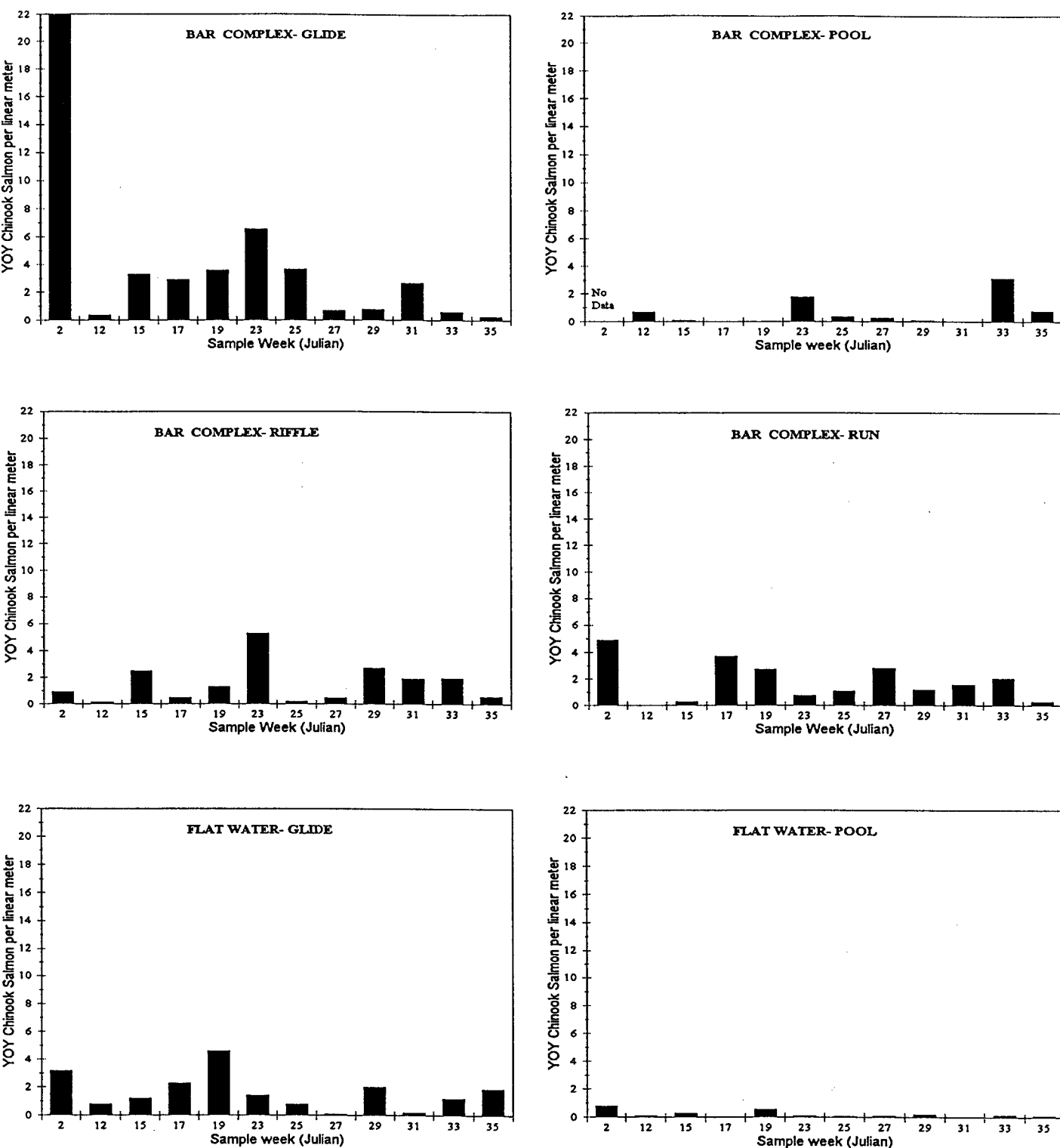
The data collected thus far have been compiled and are presented in Table 3 and Figures 1-4. The total number of YOY salmon counted for each sampling period ranged from 271 to 4885. The trend over time indicates that each race (fall-, late fall-, and winter-run) appeared in the samples near their expected time of emergence and each race appears to be represented throughout the sampling period. As of this writing the largest number of YOY still present in the study area are probably late fall-run (measuring 50-80 mm). Relatively large numbers of fall-run YOY (assumed to be most of those that now measure greater than 80 mm) also are present and winter-run YOY have recently begun to appear. Although an extensive data analysis has not been performed yet, there does not appear to be significant habitat segregation based on fish size. YOY salmon were found to occupy similar microhabitats throughout their development and large groups of fish observed later in the sampling period frequently contained individuals of all size classes.

Preliminary analyses indicate that mesohabitat type may have little to do with YOY habitat selection. Many of the mesohabitats contained significant numbers of fish and of these, none stood out as being particularly important compared to the others. This conclusion is supported in Figure 1 which presents total YOY salmon counts per linear meter of each mesohabitat type for the entire sampling period and in Figure 2 which presents the data for each sampling period (week). Some of the mesohabitats do, however, appear to receive little use by YOY. It is unclear at this time exactly why this was the case although it appears that cover availability in the various mesohabitat types may play a role. The data suggest a strong association between YOY presence and cover availability (Figure 3), particularly that which provided both velocity refugia and overhead visual isolation (compound cover). While fish were found in areas with no cover or cobbles only, a much larger proportion of those observed were using areas with compound cover. Since a substantial area lacking compound cover was sampled, it appears that this variable is an important habitat component for YOY rearing. The mesohabitat types which were infrequently used tended to have much less of this type of cover. Water velocities which were either too high or too low may also explain the avoidance of certain mesohabitats. Side-channel runs, for example, generally had minimal structural complexity to break velocities along the channel margins while the off-channel areas had no moving water to convey invertebrate drift or prevent excessive warming of the water.

There was no evidence that the relative use of a certain mesohabitat type changed much from segment to segment. Throughout the study period, all mesohabitats in the upper segment (segment 1) had more YOY salmon residing in them than the same types in segment 2 and mesohabitats in the third segment were infrequently occupied by rearing fish (Figure 4). It was not possible at this time to discern any distinct downstream migration patterns.



*Figure 1.* Average number of young-of-the-year (YOY) chinook salmon observed per linear meter of bank in each mesohabitat type in the Sacramento River for all sample dates combined during 1996. Data are means, thin lines indicate one standard error,  $n = 12$ .



*Figure 2.* Average number of young-of-the-year (YOY) chinook salmon observed per linear meter of bank in each mesohabitat type in the Sacramento River for each sample week during 1996.

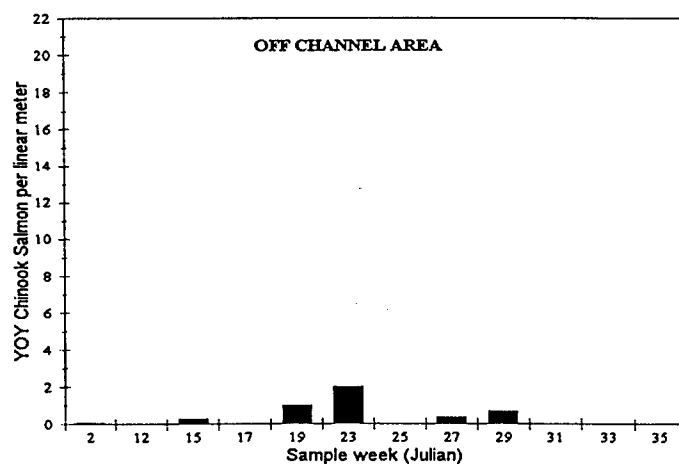
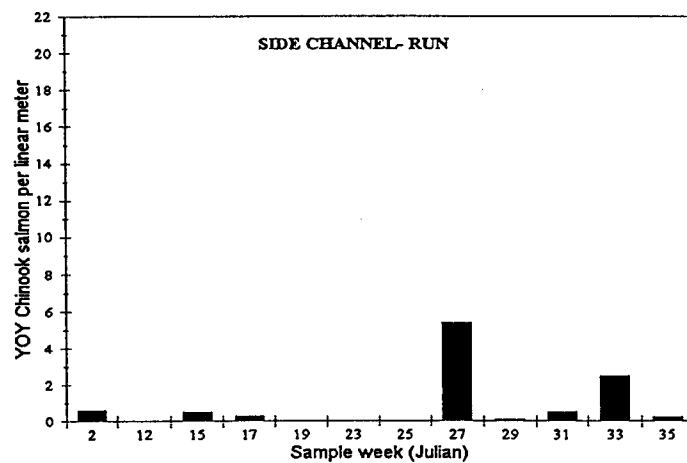
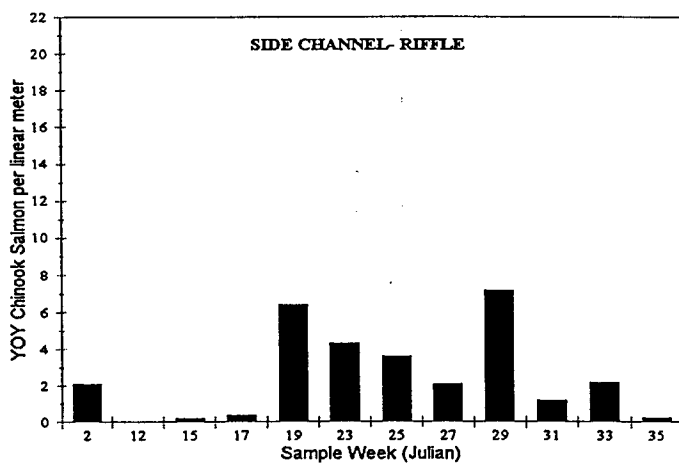
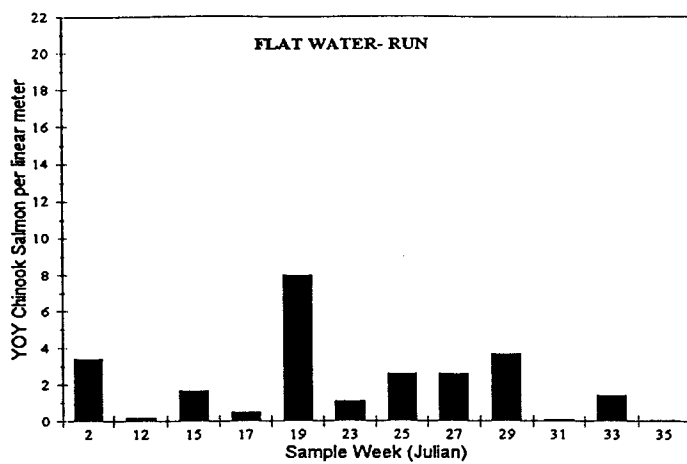
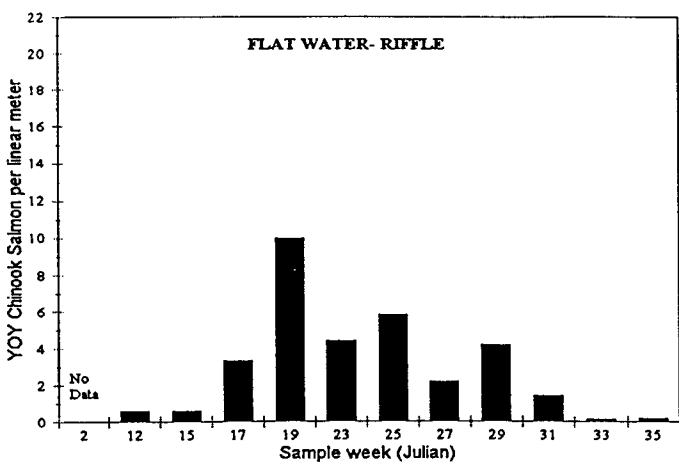
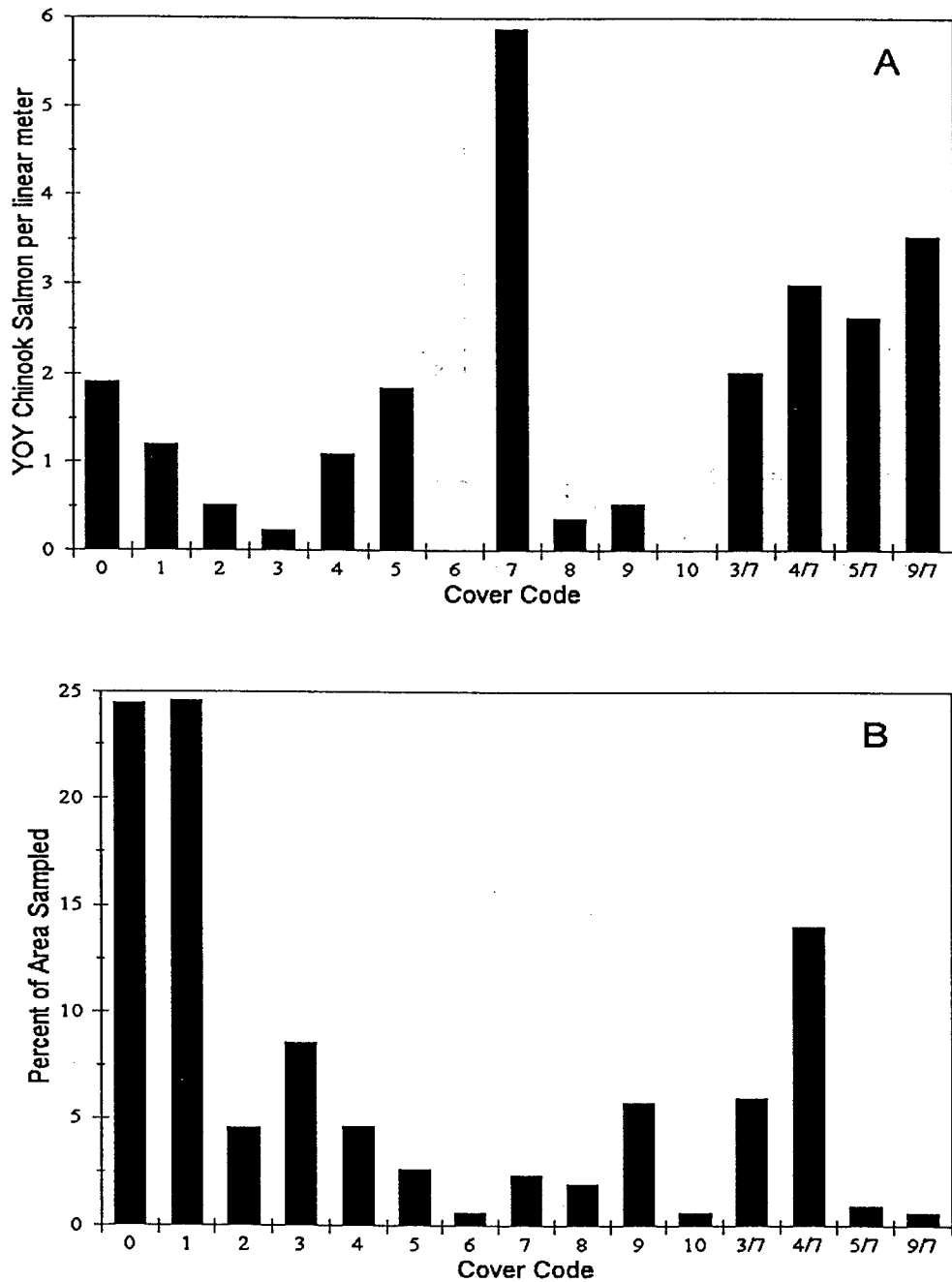
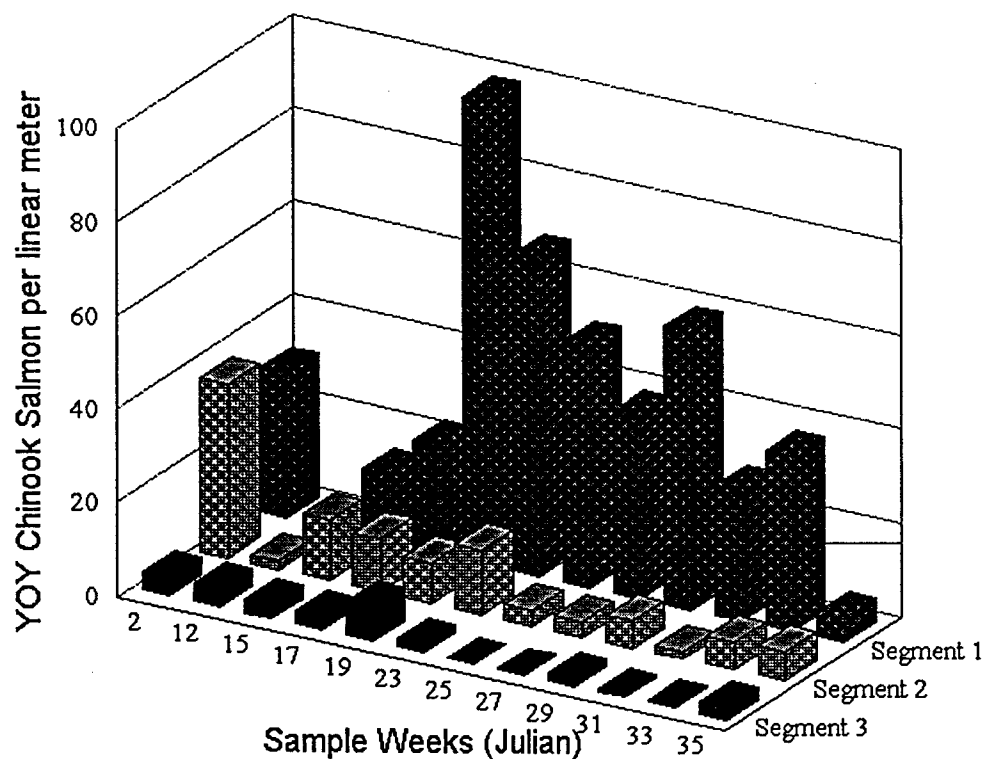


Figure 2. Average number of young-of-the-year (YOY) chinook salmon observed per linear meter (cont'd) of bank in each mesohabitat type in the Sacramento River for each sample week during 1996.



*Figure 3.* Chinook salmon young-of-the-year (YOY) cover use in the Sacramento River during 1996. A) Chinook salmon YOY per linear meter of cover type. B) Percentage of area of each cover type sampled. Cover codes are described in Table 4.



*Figure 4.* Total number of young-of-the-year (YOY) chinook salmon observed per linear meter of bank in the three segments in the Sacramento River during 1996.

## Habitat Suitability Criteria (HSC) Development

### *Spawning*

#### Methods

Depth, velocity and substrate data were collected on fall-run chinook salmon redds between October 23 and November 2, 1995. All data were entered into a spreadsheet for eventual analysis and development of Suitability Indices (HSC). Areas where significant spawning activity was known to occur were sampled and other areas were reconnoitered to check for spawning activity. An attempt was made to include most of the mesohabitat types in this



sampling to maintain an equal effort sampling design. For most redds, measurements were taken by wading with a wading rod and a Price-AA velocity meter equipped with a current meter digitizer. A few measurements (less than 10 redds) were made in deeper and/or faster water than could be waded, by holding a jet boat in position adjacent to the redd, and measuring the depth and velocity with a Price-AA meter attached to a bomb/cable/winch assembly. The number of measurements made using this technique was limited by the ability to visually locate redds in deeper water. Typically, redds could not be conclusively identified in water deeper than five to six feet and the deepest redd measured was at a depth of 5.7 feet. Fall-run chinook salmon redds have been observed in the Sacramento River in water up to ten feet deep (Larry Hanson, CDFG, personal communication). Efforts are planned to locate fall-run redds in deeper water. The options being considered are the same as those discussed below for the winter-run.

All of the active redds (those not covered with periphyton growth) within a given mesohabitat unit were measured. Data were collected from an area adjacent to the redd which was judged to have a similar depth and velocity as was present at the redd location prior to redd construction. This location was generally about two to four feet upstream of the pit of the redd; however it was sometimes necessary to make measurements at a 45 degree angle upstream, to the side, or behind the pit. The data were always collected within six feet of the pit of the redd. Depth was recorded to the nearest 0.1 ft and average water column velocity was recorded to the nearest 0.01 ft/s. Substrate was visually assessed for the dominant particle size and particle size range (e.g., dominant size of 2" and range of 1-2"). Substrate embeddedness data were not collected because the substrate adjacent to all of the redds sampled was predominantly unembedded. Sacramento River flows (releases from Keswick Reservoir) averaged 5,000 cfs  $\pm$  5% from October 10 through November 2. Since few fall-run salmon had started constructing redds prior to October 10, these steady flow conditions ensured that the measured depths and velocities were likely the same as those present at the time of redd construction. In addition, many of the measured redds still had adult salmon holding nearby, providing further indication of recent redd construction. Fall-run spawning HSC data collection will continue during the 1996 and 1997 spawning seasons.

Due to extremely high flows and turbidity from mid-January through late March, it was impossible to collect any late fall-run HSC data. Keswick releases ranged from 5,000 to 55,000 cfs during this period. Discussions have ensued relating to the inclusion of a late fall-run spawning habitat analysis in this study. This time of year, typically the winter storm season in the Sacramento Valley, will definitely present data collection problems if conditions similar to those present in 1996 persist. The effort to collect spawning HSC data for the late fall-run will continue for the 1997 and 1998 spawning seasons, river conditions permitting.

For winter-run chinook salmon, it was not possible to collect spawning HSC data in shallow water using the same techniques as were used for the fall-run. This was due to the scarcity of this race and fluctuating flow conditions. A few redds were observed but with frequently changing flow conditions there was uncertainty as to what conditions were present when the redd

was excavated. Also, redds located during CDFG helicopter surveys could not be found on the ground (Larry Hanson, CDFG, personal communication). In early June, an effort to collect winter-run spawning data from redds located in deep water (> 6 ft) was initiated with staff from the Northern Central Valley Fish and Wildlife Office (NCVFWO). SCUBA divers were pulled behind a jet-powered boat while grasping plexiglass planing boards which enabled the divers to maneuver just above the river bottom. The divers were in constant radio contact with the boat and with each other at all times. When a potential redd was located, the boat ceased forward movement and remained stationary in the current while the divers closely examined the area in question. The location of the divers on the bottom was marked by a small pontoon raft (also pulled by the dive boat with a rope the same length as those which pulled the divers) which followed above them. If the redd was confirmed as fresh, the dive boat pulled forward 10 feet, and a chase boat, equipped with an Acoustic Doppler Current Profiler (ADCP), pulled up to the location where the redd was found. With the chase boat holding in that location, the depth and velocity were measured with the ADCP, while the divers relayed the substrate information. Unfortunately, only one fresh redd was found and measured despite three days of effort. Because the dive operation represented an extreme expense of time and manpower, and because there is great interest in quantifying winter-run habitat availability, the potential for locating redds in deep water using underwater video equipment is being investigated.

Staff went to Idaho and Washington to observe a demonstration and speak with users of underwater video equipment which has been used by the USFWS, Idaho FRO and Battelle for gravel surveys and to locate redds in deep water in the Snake River drainage. The equipment consists of one or two waterproof remote cameras mounted on an aluminum frame with two 30-lb. bombs. The frame is attached to a cable/winch assembly, while a separate cable from the remote camera(s) is connected to two TV monitors through a video camera on the boat. One of the monitors is used by the boat operator to hold position on a redd, while the other is used by the winch operator to locate redds and determine the substrate size. If the video equipment was mounted on the jetboat we use to deploy the ADCP, redds could be located and measured by a three-person crew and large areas of the river could be sampled in a fraction of the time spent using the dive-planing technique described above. In addition to using this equipment for winter-run data collection, it would also be used to search deeper water for redds constructed by the other races and to collect structural (i.e. substrate and cover) data along transects placed in deeper water for habitat modelling.

For sturgeon, staff developed spawning HSC for white sturgeon in the Sacramento River using a Delphi Analysis. A Delphi Analysis is a technique used to develop HSC from information other than direct field observations (Category I criteria). Details on the methods used are contained in the Sacramento River White Sturgeon Spawning Criteria final report (Appendix A).

## Results

Data were collected on a total of 205 fall-run chinook salmon redds. Twelve mesohabitat units were sampled including four Flat Water (FW) Glides, one Side-Channel (SC) Riffle, four Bar Complex (BC) Riffles, one FW Run, one BC Run, and one SC Run. As mentioned above, no data were collected for the late fall-run. The entire channel width of the upper 900 feet of Mesohabitat Unit #139 (FW Pool), all of Mesohabitat Unit #140 (FW Glide), and half of the channel width of the lower 1,100 feet of Mesohabitat Unit #141 (Boulder Run) were searched for winter-run redds using the dive planing technique described above. Only one was located and measured.

Final results of the Sacramento River White Sturgeon Spawning Criteria Delphi Analysis are presented in Appendix A.

## *Rearing*

## Methods

HSC data were collected for chinook salmon fry and juveniles (YOY) between April 10 and June 27, 1996. Data were collected during two weeks when Keswick releases were approximately 5,000 cfs, one week when releases were around 7,000 cfs, one week when releases were around 14,000 cfs, and one week when releases were around 12,000 cfs. Either the 45.7 m (150 ft) transects used for the snorkel surveys or 45.7 m sections directly above those transects were sampled. Most of the effort was concentrated in areas adjacent to the bank for reasons discussed previously in this report. One person would snorkel along the bank and place a weighted, numbered tag at each location where YOY chinook salmon were observed. The snorkeler would record the tag number, the cover code<sup>10</sup> and the number of individuals observed in each 10 mm size class. Cover availability in the transect cell would also be recorded (same technique as was used in the snorkel survey). Another individual would retrieve the tags, measure the depth and mean water column velocity at the tag location, and record the data for each tag number. Depth was recorded to the nearest 0.1 ft and average water column velocity was recorded to the nearest 0.01 ft/s. An adjacent mean water column velocity was also measured within two feet<sup>11</sup> on either

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<sup>10</sup> If there was no cover elements (as defined in Table 4) within one foot horizontally of the fish location, the cover code was 0 (no cover).

<sup>11</sup> Two feet was selected based on a mechanism of turbulent mixing transporting invertebrate drift from fast-water areas to adjacent slow-water areas where fry and juvenile salmon reside, taking into account that the size of turbulent eddies is approximately one-half of the mean river depth (Terry Waddle, NBS, personal communication), and assuming that the mean depth of the Sacramento River is around four feet (ie., four feet x  $\frac{1}{2}$  = two feet).

side of the tag where the velocity was the highest. This measurement was taken to eventually provide the option of using an alternative habitat model (HABTAV) which considers adjacent velocities in assessing habitat quality. Adjacent velocity can be an important habitat variable as fish, particularly fry and juveniles, frequently reside in slow-water habitats adjacent to faster water where invertebrate drift is conveyed. Both the residence and adjacent velocity variables are important for fish to minimize the energy expenditure/food intake ratio and maintain growth. Data taken by the snorkeler and the measurer were correlated at each tag location and entered into a spreadsheet for eventual analysis and development of HSC. All YOY chinook salmon observed have been classified by race according to a table provided by CDFG correlating race with life stage periodicity and total length. Data were also compiled on the length of each mesohabitat and cover type sampled to ensure that equal effort would eventually be spent in each type and that each location was only sampled once at the same flow (to avoid problems with pseudo-replication). These efforts will continue over the next two years with increased effort to sample in mid-channel areas where YOY salmon have been observed in previous years by other investigators (Keith Marine, personal communication).

## Results

Two hundred eighty-two measurements (depth and velocity) were taken where YOY chinook salmon were observed. All of these measurements were made near the river banks. There were 140 observations of fish less than 40 mm, 219 observations of 40-50 mm fish, 99 observations of 50-60 mm fish, 48 observations of 60-80 mm fish and 9 observations of fish greater than 80 mm<sup>12</sup>. According to the race classification table, these numbers account for 210 fall-run and 167 late fall-run YOY chinook salmon. A total of 5.8 miles of near-bank habitat and 1.6 miles of mid-channel habitat was sampled. Table 5 summarizes the number of meters of different mesohabitat sampled and Table 6 summarizes the number of meters of different cover types sampled.

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<sup>12</sup> These numbers total much more than 282 because most of the observations included YOY of several size classes and only one measurement was made per group of closely associated individuals.

Table 5  
Distances (meters) Sampled for Juvenile Chinook Salmon HSC Data - Mesohabitat Types

Mesohabitat Type	Near-bank habitat distance sampled	Mid-channel habitat distance sampled
Bar Complex Glide	732	914
Bar Complex Pool	503	274
Bar Complex Riffle	1006	274
Bar Complex Run	823	183
Flatwater Glide	960	137
Flatwater Pool	640	0
Flatwater Riffle	1009	366
Flatwater Run	869	274
Off-Channel Area	274	0
Side-Channel Riffle	1829	82
Side-Channel Run	732	0

Table 6  
Distances (meters) Sampled for Juvenile Chinook Salmon HSC Data - Cover Types

Cover Type	Near-bank habitat distance sampled	Mid-channel habitat distance sampled
None	2262	156
Cobble	2701	1324
Boulder	643	80
Fine Woody	944	0
Branches	1629	61
Log	314	0
Depth	0	884
Overhead	182	0
Undercut	267	0
Aquatic Vegetation	389	0
Rip Rap	46	0
Overhead + instream	1810	0

## **LOWER AMERICAN RIVER**

### **Methods**

Hydraulic data collection on established transects was completed in October 1995 . These data were used to construct and calibrate hydraulic models at each study site. Data collected by CDFG on the lower American River were used to develop site-specific HSC for fall-run chinook salmon and steelhead spawning. These criteria, along with HSC developed for other California rivers, were used with the results of the hydraulic modelling to produce habitat models predicting habitat availability (weighted useable area) for spawning for the two species.

### **Results**

The final report for the study presents weighted useable area, by transect, for the 20 transects modeled at flows ranging from 1000 to 6000 cfs, using five sets of fall-run chinook salmon and two sets of steelhead spawning HSC. The final report for the study contains a details of the field techniques employed, methods and procedures followed, and the results. It was submitted to both CDFG and CVPIA Anadromous Fish Restoration Program staff on March 27, 1996.

## **MERCED RIVER**

### **Project Scoping, Field Reconnaissance and Study Site Selection**

#### **Methods**

Project scoping began in March 1996. Redd count data collected by CDFG from 1989 to 1991 and from 1993 to 1994 from the 10 miles of the Merced River below Crocker-Huffman Dam were entered into a spreadsheet and spawning areas were ranked to identify those which consistently received the heaviest spawning use by fall-run chinook salmon. Staff, along with Lester Yamaguchi of CDFG who conducted the redd counts in the last two years, conducted a field reconnaissance of the reach on July 2-3. The purpose of the reconnaissance was to investigate the suitability of the 11 highest-ranked riffles and identify, based on Mr. Yamaguchi's recollections, which portion of each riffle received the heaviest spawning use.

#### **Results**

Nine of the 11 riffles were selected for placement of study sites. One of those excluded (ranked fifth) was located below a head control wing dam and is no longer useable for spawning because the spawning gravels were removed to rebuild the wing dam after high winter flows had washed it out. Another riffle (ranked tenth) was not suitable for hydraulic modelling due to complex hydraulics and logistical problems in reaching the site. Six study sites were established, four

covering a single riffle and one including two of the top ranked spawning riffles. Another site remains to be established at, and just below, the Merced River Hatchery (this site also will include two of the top ranked riffles) as soon as gravel restoration undertaken by CDWR and CDFG are completed.

## Transect Placement

### Methods

Transects were placed in the established sites across the optimal spawning areas (primarily based on substrate particle size) using rebar driven into the ground and/or lag bolts placed in tree trunks on opposite sides of the river.

### Results

A total of 23 transects have been placed. Five to seven additional transects are expected to be placed at the Hatchery site during the week of September 30th. The study sites, CDFG riffle number, and number of transects placed at each site are shown in Table 7.

Table 7  
Merced River Fall-run Chinook Spawning Sites

Site Name	Riffle Number(s)	Number of Transects
Hatchery	1, 2	5-7(proposed)
Big Bull Flat	37, 38	5
Red's Riffle	44	3
Barn Owl Riffle	45	2
Robinson Riffle	51	6
Sodbuster Riffle	56	3
Bull Frog Riffles	60A&B	4

## **Hydraulic Data Collection**

### **Methods**

Benchmarks were established at each site to serve as the reference elevation to which all elevations (streambed and water surface) will be tied. The data collected on each transect include: 1) water surface elevations (WSELs), measured to the nearest .01 foot at three significantly different stream discharges using standard surveying techniques (differential leveling); 2) wetted streambed elevations determined by subtracting the measured depth from the surveyed WSEL at a measured flow; 3) dry ground elevations to points above bankfull discharge surveyed to the nearest 0.1 foot; 4) mean water column velocities measured at a mid-range flow at the points where bed elevations were taken; and 5) substrate classification (see codes, Table 8) at these same locations and also where dry ground elevations were surveyed. Hydraulic data collection began in mid-July.

### **Results**

At all established sites the data collected to date include low flow (70 to 150 cfs) discharge and WSELs, and ground elevations and substrate classification (Table 8) for transect cells between the low flow waters edge and the high water mark (approximately 3000 cfs). In addition, low flow depth and velocity measurements have been made and substrate classified across all transects at Red's Riffle, Barn Owl Riffle, Sodbuster Riffle and Bull Frog Riffles. The low flow velocity data, while not absolutely necessary for the hydraulic modelling, will be useful in calibrating the hydraulic models. Staff have been coordinating with CVPIA and CDFG staff to arrange releases of 400 cfs and 1000 cfs in October. If these releases occur as requested, hydraulic and structural data collection may be completed by the end of October. Also planned in October (possibly with the assistance of CDFG staff) is data collection for fall-run spawning to develop site-specific HSC. The methods which will be used to collect these data are the same as those described above for fall-run chinook spawning on the Sacramento River.

## **MISCELLANEOUS STUDY ACTIVITIES**

### **ADCP field testing**

The Broad-Band Acoustic Doppler Current Profiler (ADCP) purchased from RD Instruments near the end of FY95 was received in early November. The ADCP enables the collection of extremely detailed water velocity information from a moving boat. The ADCP uses high frequency sonar pulses to measure the speed, direction, and depth of water by calculating the Doppler shift when transmitted signals are returned from sound scatterers in the water column and from the streambed. A mounting system was fabricated for deployment from our jet boat and the instrument was extensively field tested during March, 1996 on the lower American



Table 8  
Merced River Substrate Codes

Substrate Category	Substrate Code
finer or > 75% embedded	0
gravel < 1"	1
1" - 2" gravel	2
2" - 4" gravel/cobble	3
4" - 6" cobble	4
6" - 8" cobble	5
substrate > 8"	6
aquatic vegetation	7

River. Tests were run using multiple configuration files which define the parameters for data collection. Collected data were reviewed to determine the capabilities and limitations of the ADCP over a range of hydraulic conditions. Preliminary results indicate that the instrument will collect viable hydraulic data in water equal to or greater than one three feet deep with a maximum water velocity of seven feet per second.

### Two-dimensional habitat modelling

On the Sacramento River, it has been observed that many areas of the river exhibit morphologic and hydraulic conditions which may be difficult to hydraulically model using traditional one-dimensional modelling techniques, i.e. PHABSIM. Should these areas prove to be important for certain life stages of the evaluation species, it may be difficult at best to quantify the physical habitat available in these areas. A new generation of models (two-dimensional) is currently being developed by the modelling community which can address physical complexities which PHABSIM cannot. In addition, these models are adept at identifying habitat mosaics and edge effects which are important habitat considerations when evaluations are conducted on multiple species/life stage complexes. The USGS (formerly NBS) Midcontinent Ecological Sciences Center (MESC) is currently developing two-dimensional habitat models in the upper Missouri River Basin on the Missouri and Yellowstone Rivers. In September, Jeff Thomas accompanied MESC personnel Ken Bovee, Dr. Terry Waddle, and Dr. Zachary Bowen to their study sites to collect data and investigate the possible application of two-dimensional modelling in the Sacramento River study. It is our conclusion that this approach would be useful for the study and the Instream Flow Assessments Branch is pursuing an agreement with MESC to assist in the effort. Their participation would be funded by MESC.

## **APPENDIX A**

### **SACRAMENTO RIVER WHITE STURGEON SPAWNING CRITERIA**

U.S. DEPARTMENT OF THE INTERIOR  
FISH AND WILDLIFE SERVICE

**SACRAMENTO RIVER WHITE STURGEON  
SPAWNING CRITERIA**

U.S. Fish and Wildlife Service  
Ecological Services  
Sacramento Field Office  
2800 Cottage Way, Room E-1803  
Sacramento, CA 95825



Prepared by

Mark Gard  
Instream Flow Assessments Branch

February 1996

## PREFACE

The following is the final report for the U.S. Fish and Wildlife Service's delphi analysis to develop spawning criteria for Sacramento River white sturgeon, part of the Anadromous Doubling Plan Instream Flow Investigations, a 5-year effort which began in February, 1995. Title 34, Section 3406(b)(1)(B) of the Central Valley Project Improvement Act, P.L. 102-575, requires the Secretary of the Interior to determine instream flow needs for anadromous fish for all Central Valley Project controlled streams and rivers, based on recommendations of the U.S. Fish and Wildlife Service after consultation with the California Department of Fish and Game (CDFG). The purpose of these investigations is to provide reliable scientific information to the U.S. Fish and Wildlife Service Central Valley Anadromous Fish Restoration Program to be used to develop such recommendations for Central Valley rivers.

To those who are interested, comments and information regarding this report are welcomed. Written comments or information can be submitted to:

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# SACRAMENTO RIVER WHITE STURGEON SPAWNING CRITERIA

## I. INTRODUCTION

In response to substantial declines in anadromous fish populations, the Central Valley Project Improvement Act requires the doubling of the natural production of anadromous fish stocks, including the four races of chinook salmon (fall, late-fall, winter and spring runs), steelhead, and white and green sturgeon. The Central Valley Project Improvement Act Anadromous Doubling Plan calls for February through May Sacramento River flows at Grimes of 17,700 cfs (in wet and above normal water years) for white and green sturgeon spawning.

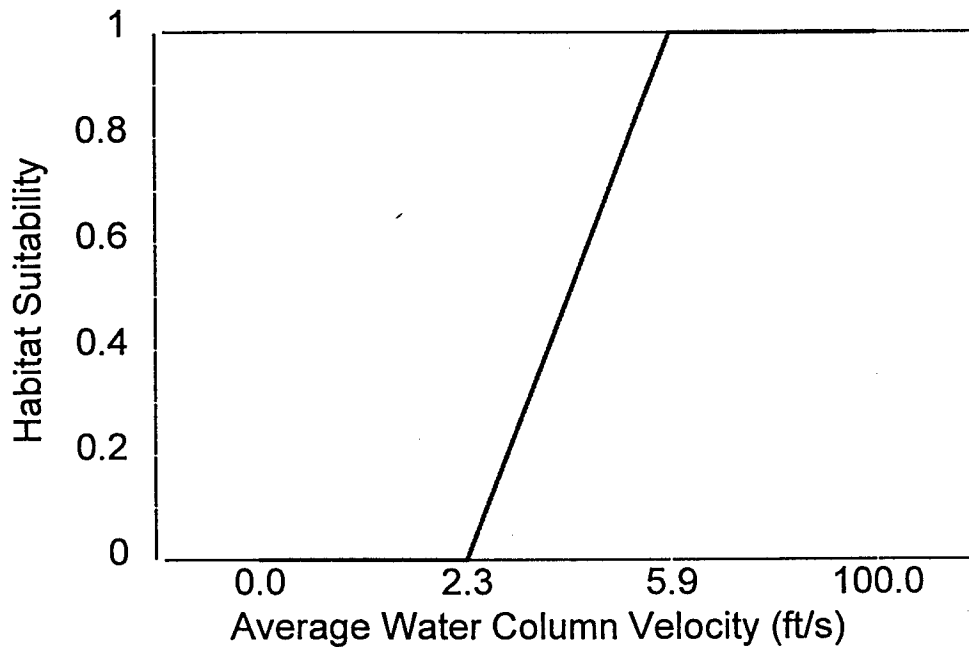
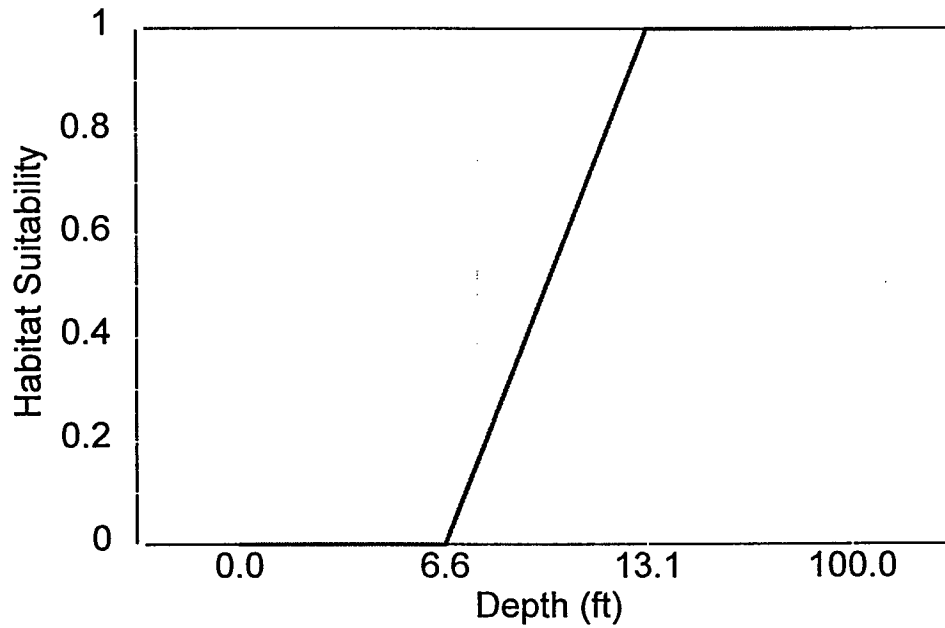
The Physical Habitat Simulation System (PHABSIM) component of the Instream Flow Incremental Methodology (IFIM) is a hydraulic and habitat model that can be used to predict physical habitat availability over a range of streamflows for various fish species and other instream activities. In this case, PHABSIM could be used to determine the relationship between Sacramento River flows and the amount of physical habitat available for white sturgeon spawning. The resulting relationship could be used to validate the above Doubling Plan flow, or to derive different recommendations for Sacramento River flows for white sturgeon spawning.

Habitat suitability criteria (HSC or SI curves) are used within PHABSIM to translate hydraulic and structural elements of rivers into indices of habitat quality (Bovee 1986). Suitability index values range from zero to one. HSC (Table 1, Figure 1) have been developed for white sturgeon spawning in the Lower Columbia River by sampling for white sturgeon eggs with spawning mats (Parsley and Beckman 1994). However, these criteria might not be transferrable to the Sacramento River because Lower Columbia River flows are more than an order of magnitude greater than Sacramento River flows, and because the Lower Columbia River criteria were developed in tailrace areas, in contrast to the areas in which criteria would likely be applied on the Sacramento River, at least 100 miles downstream of Keswick Reservoir. In addition, the

Table 1  
Lower Columbia River Substrate Suitability Criteria (from Parsley and Beckman 1994)

Substrate Type	Suitability
Sand	0
Gravel	0.5
Cobble	1
Boulder	1
Bedrock	1

Figure 1  
Lower Columbia River White Sturgeon Spawning Habitat Suitability Curves  
(from Parsley and Beckman 1994)



Lower Columbia River criteria do not have an upper limit for either depth or velocity. There could be an upper limit on velocity for sturgeon spawning because of either physiological (i.e., swimming speed limitations) or behavioral (i.e., to prevent eggs from being carried into areas with unsuitable substrates) factors. Sustained swimming speeds of various sturgeon species range from 0.2 to 4.5 body lengths per second (Beamish 1978).

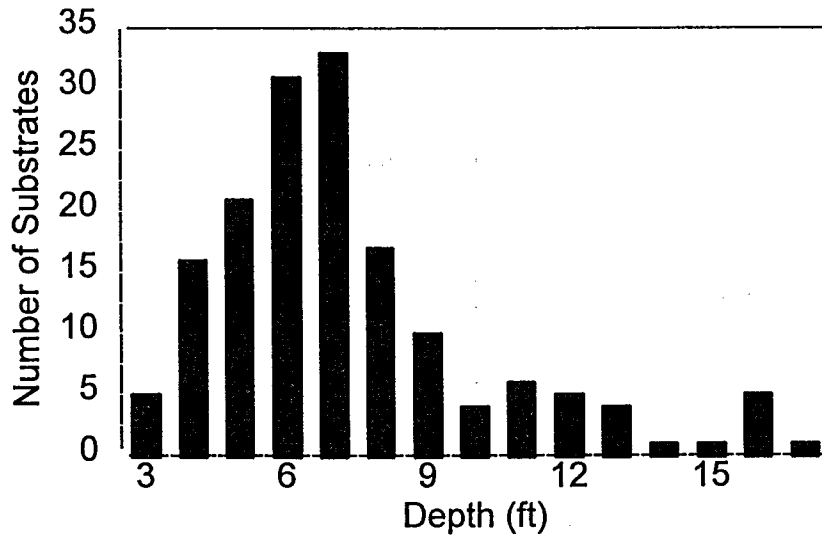
Schaffter (1994) deployed artificial substrate egg samplers of latex-coated animal hair at various locations in the Sacramento River in 1992. White sturgeon eggs were captured six times on the egg samplers (Table 2). The microhabitat characteristics of the locations where eggs were captured (Table 2) fell within the range of depths, velocities and substrate types of all of the artificial substrate egg sampling locations (Table 3, Figure 2). Larger substrate types (cobble and larger) were not sampled in 1992 (Schaffter, personal communication). The velocities in Table 2 and Figure 2 are average water column velocities, estimated using Schaffter's (1994) measurements of velocity (30 cm off of the bottom), the water depth, and the 1/mth power law equation (Milhous et al 1989).

Table 2  
Characteristics of Spawning Mat Locations Where White Sturgeon Eggs Were Collected  
Data adapted from Schaffter (1994)

Number of eggs collected	Water Depth (ft)	Average Water Column Velocity (ft/s)	Substrate
1	5	4.67	50% gravel, 50% cobble
1	8	5.81	gravel
2	6.7	4.68	gravel
5	6.3	4.51	gravel
7	5.8	4.76	gravel
19	13	5.17	gravel

Figure 2  
Data Adapted from Schaffter (1994)

Sacramento River Sturgeon Spawning  
Substrate Sampling Distribution



Sacramento River Sturgeon Spawning  
Substrate Sampling Distribution

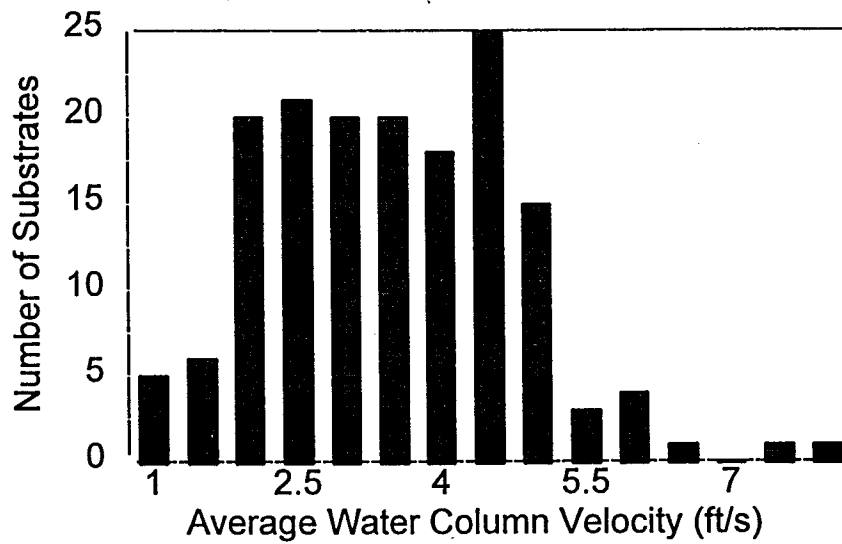




Table 3  
Sacramento River Sturgeon Spawning Substrate Sampling Distribution  
(data from Schaffter 1994)

Substrate Type	Frequency of Substrates Sampled
Sand	29
80% sand, 20% gravel	8
50% sand, 50% gravel	22
10% sand, 90% gravel	1
gravel	91
50% gravel, 50% cobble	9

## II. METHODS

Since there were not sufficient data available to develop site-specific criteria for white sturgeon spawning in the Sacramento River (Category II criteria), it was decided that Category I criteria should be developed for white sturgeon spawning in the Sacramento River using a delphi analysis. A delphi analysis (Bovee 1986) is an iterative process where a group of experts are polled, with controlled feedback provided, the goal being a consensus among the group. Seven experts were identified who had experience using sampling mats to collect microhabitat use data for white sturgeon spawning: 1) Mike Parsley, Columbia River Research Laboratory, NBS; 2) Ray Schaffter, CDFG Stockton; 3) George McCabe, NMFS; 4) Jim Chandler, Idaho Power Company; 5) Paul Anders, Kootenai Tribe of Idaho; 6) Larry Hildebrand, RL&L Environmental Services LTD; and 7) Vaughn Paragamian, Idaho Department of Fish and Game. All of these experts agreed to participate in the delphi analysis.

In the first round of the delphi analysis, the participants were sent an information request, presenting the above information, and asking them to fill in three tables. These tables were refined slightly during the analysis to make the questions more clear and (based on the suggestion of one participant) add an additional substrate category. The appendix of this report is the final version of the three tables. In the subsequent three rounds, the participants were given the opportunity to revise their earlier responses based on a summary of the group's responses (specifically, the median and first and third quartile responses to each question). Respondents were asked to explain the basis for their response if it was less than the first quartile or greater than the third quartile of the group's responses to the previous round. The participants were also invited to provide any additional information or to write any comments,

ideas or logic that they used in their answers. All such information was summarized and presented to the participants in the next round. All responses were kept anonymous. The delphi analysis was ended after the fourth round based on a qualitative evaluation of the stability of individual's responses and a quantitative measure of the degree of convergence (for depth and velocity responses). Specifically, the quantitative measure was the average (for all depth and velocity questions) of the coefficient of variation (the standard deviation divided by the mean) of the responses for each question. The median values in the last round were used as the final Category I criteria. In the last round, the respondents were also polled on the degree to which various factors influenced their responses.

### III. RESULTS/DISCUSSION/CONCLUSIONS

The final Category I Sacramento River white sturgeon spawning criteria, which, as noted above, were the median responses for the last round of the delphi analysis, are given in Tables 4 and 5 and Figure 3. The quantitative measure of the degree of convergence of depth and velocity responses had values of 0.56, 0.21, 0.10 and 0.09 for the four rounds, demonstrating that there was a movement towards consensus during the delphi analysis, and that convergence changed little between the third and fourth rounds. The latter conclusion is consistent with a qualitative evaluation that individuals' responses changed very little between the third and fourth rounds. With the exception of one individual, there was complete consensus on all of the substrate SI values by the last round, except for the SI value for snags. Even for this substrate category, excluding the above individual, the range of responses was from 0.3 to 0.4. Accordingly, we conclude that there was success in reaching consensus.

Based on the questions posed to the respondents in the last round of the delphi analysis, the SI curves developed for the Lower Columbia River (Parsley and Beckman 1994) and data from other rivers (with mean values of the responses for these, respectively, of 3.7 and 3.8, on a scale of 1 to 5) had more influence on their responses than data from the Sacramento River or responses of the other delphi analysis participants (mean values, respectively, of 2.8 and 2.2). The final Category I criteria are generally consistent with the data in Table 2; specifically: 1) all of the velocity values in Table 2 have SI values greater than 0.5, and two have SI values of 1.0; 2) three of the depth values in Table 2 have SI values between 0.5 and 1.0, and one has an SI value of 1.0; and 3) the substrate values in Table 2 have SI values of at least 0.5. The only slight inconsistency is that one of the depth values in Table 2 (5 feet) has an SI value of 0, but this is highest depth that has an SI value of 0. The consistency of the substrate data in Table 2 with the substrate SI values is difficult to completely evaluate, given that no substrates with SI values of 1.0 were sampled by Schaffter (1994).

Given that there are some differences between the Category I Sacramento River white sturgeon spawning criteria and the Category II Lower Columbia River white sturgeon spawning criteria (Parsley and Beckman 1994), it would be useful to collect at least enough additional spawning mat data from the Sacramento River to conduct a transferability test (Thomas and Bovee

1993), to see which, if either, of the two above criteria are transferable to the Sacramento River. Ideally, given sufficient resources, enough additional spawning mat data could be collected from the Sacramento River to develop Category II Sacramento River white sturgeon spawning criteria. At the very least, the Category I Sacramento River white sturgeon spawning criteria can be used with habitat availability data to assess, using PHABSIM, the relationship between Sacramento River flows and weighted useable area for white sturgeon spawning. Since the Category I criteria suggest that white sturgeon are limited to spawning in deep, fast areas with large substrates, transects for simulating available habitat should be selected in these types of areas.

Table 4  
Sacramento River White Sturgeon Spawning Criteria for Velocity & Depth

Velocity (ft/s)	SI Value	Depth (ft)	SI Value
0	0	0	0
2.3	0	5	0
3.9	0.5	6	0.5
5	1	10	1
12.5	1	100	1
19.95	0.5		
25.5	0		
100	0		

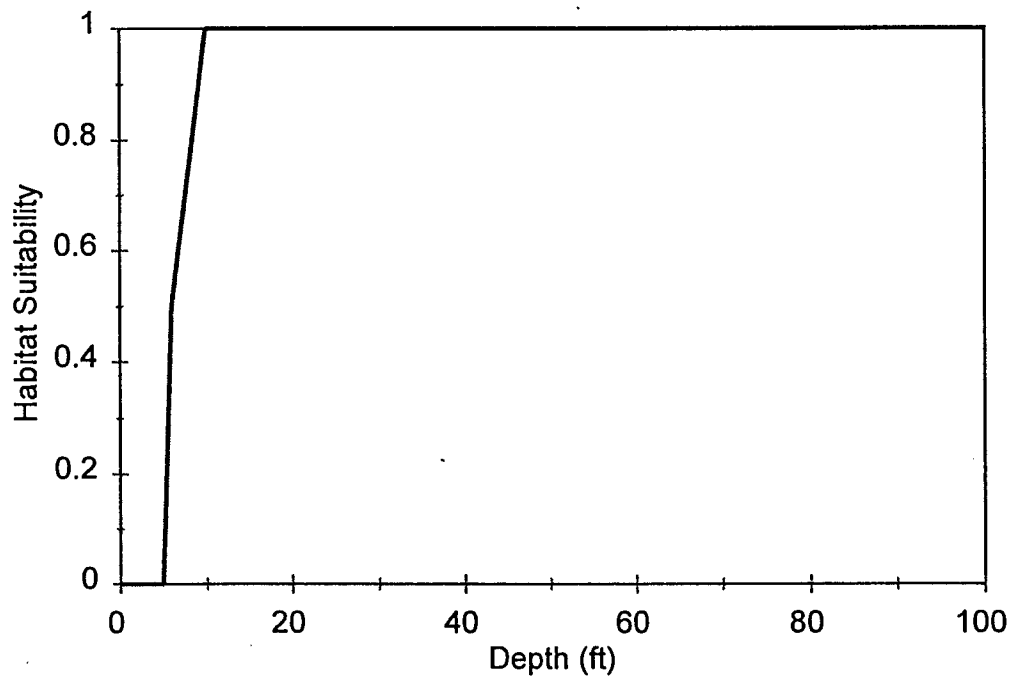
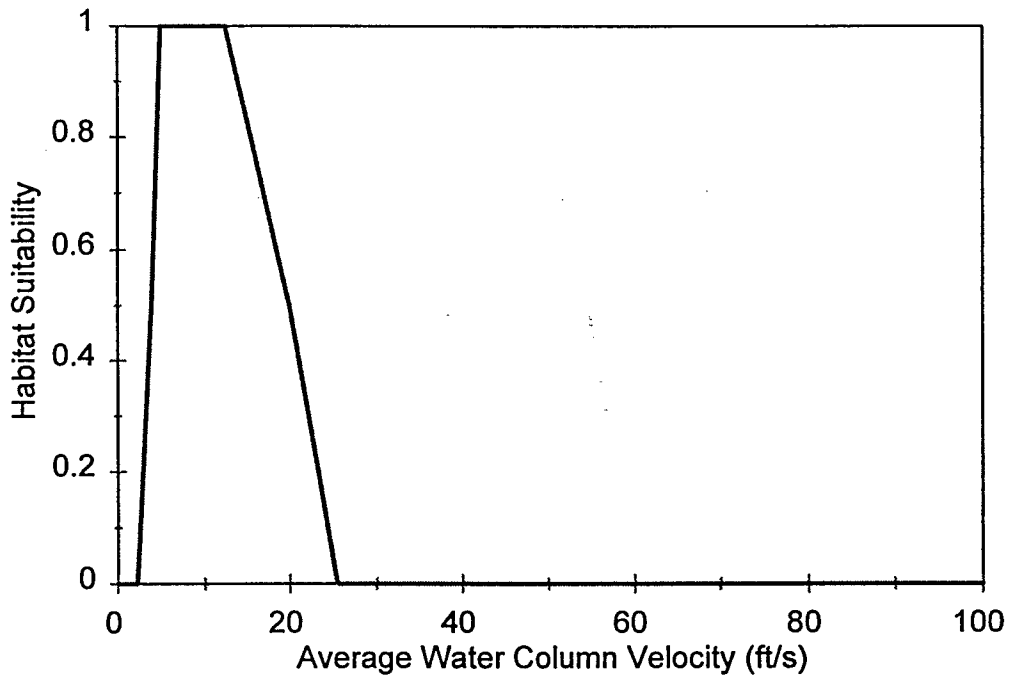
Table 5  
Sacramento River White Sturgeon Spawning Criteria for Substrate

Substrate Type	Substrate Particle Size	Suitability Index
snags	---	0.35
other plant detritus	---	0
compacted clay	---	0
silt/fine clay	< 0.02"	0
sand	0.02 - 0.1"	0
gravel	0.1 - 2.5"	0.5
cobble	2.5 - 10"	1
boulder	10" - 12'	1
bedrock	> 12'	1

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Figure 3  
Sacramento River White Sturgeon Spawning Habitat Suitability Curves



**APPENDIX  
INFORMATION REQUEST TABLES**

Velocity Condition	Average Water Column Velocity (ft/s)
Lowest velocity considered to be optimal	
Highest velocity considered to be optimal	
Level velocity must decrease to for Suitability Index = 0 (use N if never occurs)	
Level velocity must increase to for Suitability Index = 0 (use N if never occurs)	
Level velocity must decrease to for Suitability Index = 0.5 (use N if never occurs)	
Level velocity must increase to for Suitability Index = 0.5 (use N if never occurs)	

Depth Condition	Total Water Column Depth (feet)
Lowest depth considered to be optimal	
Highest depth considered to be optimal	
Level depth must decrease to for Suitability Index = 0 (use N if never occurs)	
Level depth must increase to for Suitability Index = 0 (use N if never occurs)	
Level depth must decrease to for Suitability Index = 0.5 (use N if never occurs)	
Level depth must increase to for Suitability Index = 0.5 (use N if never occurs)	

Substrate Type	Substrate Particle Size	Suitability Index
snags	---	
other plant detritus	---	
compacted clay	---	
silt/fine clay	< 0.02"	
sand	0.02 - 0.1"	
gravel	0.1 - 2.5"	
cobble	2.5 - 10"	
boulder	10" - 12'	
bedrock	> 12'	